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Tidal Remnants and Intergalactic H II Regions

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Abstract.

We report the discovery of two small intergalactic H II regions in the loose group of galaxies around the field elliptical NGC 1490. The H II regions are located at least 100 kpc from any optical galaxy but are associated with a number of large HI clouds that are lying along an arc 500 kpc in length and that have no optical counterpart on the Digital Sky Survey. The sum of the HI masses of the clouds is almost $10^{10} M_{\odot}$ and the largest HI cloud is about 100 kpc in size. Deep optical imaging reveals a very low surface brightness counterpart to this largest HI cloud, making this one of the HI richest optical galaxies known ($M_{\text{HI}}/L_V \sim 200$). Spectroscopy of the H II regions indicates that the abundance in these H II regions is only slightly sub-solar, excluding a primordial origin of the HI clouds. The HI clouds are perhaps remnants resulting from the tidal disruption of a reasonably sized galaxy, probably quite some time ago, by the loose group to which NGC 1490 belongs. Alternatively, they are remnants of the merger that created the field elliptical NGC 1490. The isolated H II regions show that star formation on a very small scale can occur in intergalactic space in gas drawn from galaxies by tidal interactions. Many such intergalactic small star formation regions may exist near tidally interacting galaxies.

1. Introduction

Hierarchical accretion and merging of small clumps appears to be a good description of the formation of early-type galaxies. In many early-type galaxies signatures of recent hierarchical assembly can be observed, particularly in field galaxies. Optical fine structure -shells, dust lanes, “X” structures- revealed through un-sharp masking of optical images suggests a recent accretion event. These fine structures are correlated with the presence of an intermediate age (1-2 Gyr) population of stars (e.g. Schweizer et al. 1990). Moreover, comparing detailed stellar population models with high signal-to-noise optical spectra indicates the presence of an intermediate age population in several early-type galaxies (e.g. Trager et al. 2000). A small but significant fraction of early-type galaxies contain neutral hydrogen. The origin of this neutral hydrogen is generally thought to be external and due to recent accretion of companions. Hence the presence of HI in early-type galaxies is generally thought to fit into the picture of continued accretion of companions and the associated intermittent episodes of star formation in some early-type galaxies.

We are undertaking a systematic HI survey, using the Australia Telescope Compact Array (ATCA), of *all* early-type galaxies south of $\delta < -25^\circ$ with $V < 6000 \text{ km s}^{-1}$ (based on HIPASS, the Parkes All Sky HI Survey, see Barnes et al. 2001 and elsewhere in this volume) to obtain an unbiased sample of HI-rich early-type galaxies. Such a complete sample will allow us to study the effects of HI on the evolution of early-type galaxies in different environments, and the relation between HI and other indicators of recent accretion and star formation (see also Sadler et al. 2002). We can also study whether HI always has an external origin in early-type galaxies or whether in some early-type galaxies the HI may be related to an earlier phase in the evolution of the galaxies.

During this HIPASS follow-up program we discovered two intergalactic HII regions near the field elliptical NGC 1490 that are probably related to merging/accretion within the loose group of galaxies around NGC 1490, or to the merger that created the field elliptical NGC 1490. Although unusual, these regions seem to fit into the generally accepted picture regarding HI in early-type galaxies. We discuss these HII regions in section 2. However, we find some evidence that some early-type galaxies do not fit into the scheme of continued accretion. This we briefly discuss in section 3.

2. Intergalactic HII regions near NGC 1490

The HIPASS spectrum of NGC 1490 shows a strong detection with the presence of almost $10^{10} M_\odot$ of neutral hydrogen. This detection was followed up with deep HI observations performed with the ATCA to image the HI in the region around NGC 1490. Five objects were detected with a total HI mass of $8.9 \times 10^9 M_\odot$ (Figure 1). Only one HI cloud has an obvious counterpart (cloud 4) on the Digital Sky Survey in the form of a small galaxy. The other HI clouds seem to lie along an arc of more than 500 kpc long that bends around NGC 1490. About half of the total amount of HI is found in one cloud of about 100 kpc in size (cloud 1). Fig. 2 shows a position-velocity plot of two HI clouds, as marked in Fig. 1. The kinematics of the HI clouds indicates that they are separate entities.

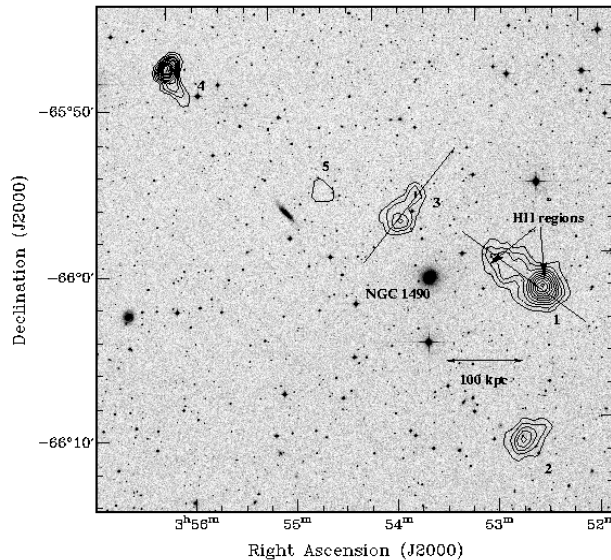


Figure 1. View of the entire region around NGC 1490, displaying the 5 objects detected in HI. Contour levels: $2, 4, 6, \dots \times 10^{19} \text{ cm}^{-2}$. The lines indicate the orientation along which the position-velocity plots of Fig. 2 are taken.

E.g. the velocity gradient in cloud 3 is perpendicular to the line connecting the neighbouring clouds. The “U-shaped” pattern observed in the largest HI cloud indicates that this cloud is not in rotational equilibrium.

Deep optical imaging was performed in a number of standard filters of the region of this largest HI cloud, using FORS1 on the VLT. This imaging reveals a very low surface brightness optical counterpart (the “OC”). The peak surface brightness in the V band is $24.5 \text{ V mag arcsec}^{-2}$. The low surface brightness nature of the OC is illustrated in Fig. 3. The total magnitude is about 20.5 in V. This implies an extremely high gas-to-light ratio of $M_{\text{HI}}/L_V \sim 200$. For the colour indices we find $U_B = 0.5$, $B_V = 0.1$, $V_R = 0.4$ and $R_I = 0.6$. These colours indicate the presence of a young stellar population.

We further investigated the nature of the main HI cloud and its OC by searching for the presence of $\text{H}\alpha$ emission using narrow-band $\text{H}\alpha$ imaging with the NTT. These images reveal the presence of $\text{H}\alpha$ emission in the OC at the location of the peak of the HI, indicating that some star formation is occurring in the OC. Most interestingly, two small regions of $\text{H}\alpha$ emission were found at the edge of the main HI cloud, at a distance of about 100 kpc from the OC (indicated by 1 & 2 in Fig. 3). The broad-band images indicate that there is no extended optical continuum light near these two $\text{H}\alpha$ regions.

The $\text{H}\alpha$ luminosities of the HII complexes are $3 - 5 \times 10^{38} \text{ erg s}^{-1}$ (i.e. 30-50 times Orion). The rate of star formation estimated from these luminosities is very modest: around 0.005 Myr^{-1} per region. All the stars corresponding to the

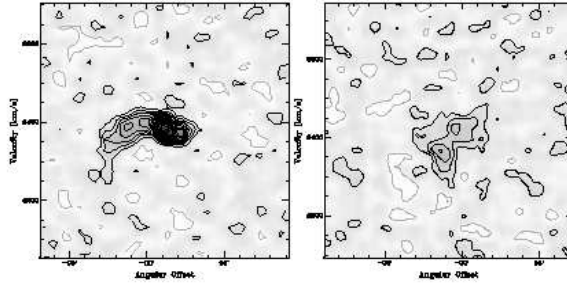


Figure 2. Position-velocity plots of clouds 1 and 3, taken along the line indicated in Figure 1. Contour levels are $-1, 1, 2, 3, \dots$ mJy beam^{-1}

diffuse optical counterpart can be formed over a Hubble Time with such a star formation rate.

Optical spectroscopy of the three $\text{H}\alpha$ regions was performed with FORS1 on the VLT. Preliminary analysis of the data suggests that the abundances in the $\text{H}\alpha$ regions are only slightly below solar (in the range $0.5\text{--}1.0 Z_{\odot}$). This relatively high abundance excludes a primordial nature of the HI clouds.

2.1. The nature of the clouds near NGC 1490

The observations point to a tidal- or merger-related origin for the system of HI clouds near NGC 1490. The alternative hypothesis, i.e. the HI clouds are primordial, can be excluded because of the near solar abundance measured in the HII complexes. The arc-like arrangement of the HI clouds is suggestive for a tidal origin. It bears some resemblance to other systems. There is probably a parallel between the objects discussed here and systems like e.g. the Leo Ring (Schneider et al. 1989). Tidal interactions between galaxies and merging is a very diverse process that can produce very spectacular objects with bright tidal tails. But there are also cases where the evidence of an interaction is only detectable in neutral hydrogen. The extreme version is that of a galaxy being completely destroyed by a larger galaxy without any merging taking place. The material of the original galaxy is spread out over such a large volume that, in the optical, the surface brightness is well below the detection limit and only the HI remains observable (e.g. Ryan-Weber et al. 2003, see also this proceedings). Perhaps the HI clouds near NGC 1490 have such an origin.

An alternative hypothesis is that the HI clouds are remnants of the merger between two or more gas-rich galaxies that also created the field elliptical NGC 1490. The environment of NGC 1490 can be characterised as a loose group. The presence of an elliptical galaxy in such a group often indicates that merging has occurred in the group.

The interesting aspects of the case presented here are:

1) the very large amount of HI involved, distributed in fairly large clouds for which only deep optical imaging reveals an optical counterpart. As the velocity structure indicates, these clouds are separate entities, suggesting they are Tidal

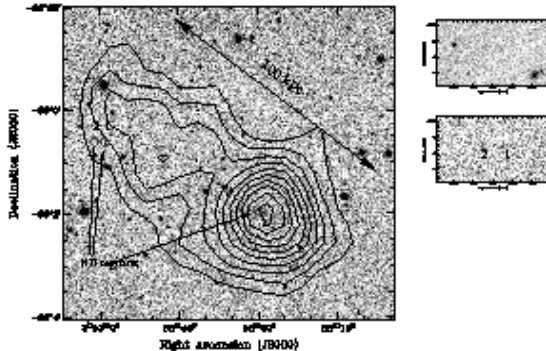


Figure 3. *Left* HI contours on top of an r -band image obtained with the NTT. Contour levels are as in Fig. 1. The location of the three HII complex discovered using the narrow-band imaging are indicated. *Right* Continuum optical image (top) centred on the regions 1 and 2 and the continuum subtracted line image, centred on the redshifted $H\alpha$, revealing the two HII complexes (bottom)

Dwarfs even though they have no bright optical counterpart. The clouds are not, or hardly, visible in the optical, but, given the large reservoir of HI, perhaps at some point in time they will start to make stars and become brighter optical objects.

2) the existence of an extremely gas-rich object with $M_{\text{HI}}/L_V \sim 200$. This is perhaps an example of a "Tidal Gas Cloud" that started making stars recently. However, it is perhaps more likely that the optical material originates in a galaxy that was destroyed in an interaction.

3) the presence of small HII complexes that are located far away from any optically detectable galaxy, in our case more than 100 kpc. Only very few examples of such HII regions are known. The observations presented here suggest that in more systems intergalactic HII complexes may exist.

3. Non-accretion origin of HI in some early-type galaxies?

As a final remark, we note that, although the results discussed above fit very well into the picture continued accretion by early-type galaxies, and the associated external origin of HI in early-type galaxies, we have found some indications that some early-type galaxies do not fit into this scheme. Our survey has revealed a surprisingly large number of early-type galaxies that have very large (up to 200 kpc in size), regular disks of low column density HI. In Fig. 4 we present three examples of such large regularly rotating HI disks. The largest of these disks have HI masses up to $10^{10} M_{\odot}$. Given their size and regular appearance, these

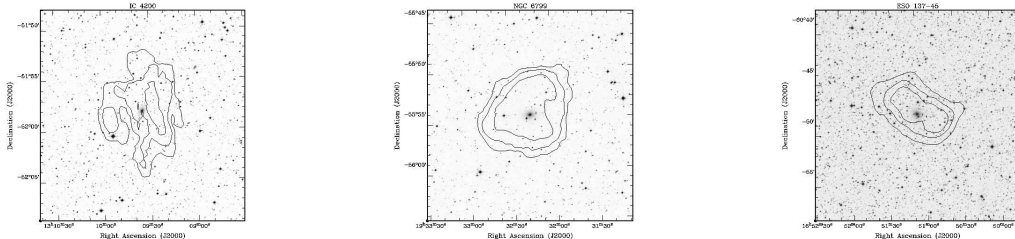


Figure 4. Examples of very large regular disks of HI distribution around “normal” early-type galaxies obtained from the ATCA follow up of HIPASS detections (see text for details). The disks shown here have sizes between 150 and 200 kpc. Contour levels: $2, 4, 8, 16 \times 10^{19} \text{ cm}^{-2}$.

disks must be quite old, in many cases well over 5×10^9 yr. Hence, they are not related to recent accretions and may be related to a much earlier formation phase of these galaxies. Moreover, no large accretion can have occurred by these galaxies, as these would likely have destroyed these large HI disks, or have triggered significant star formation in the HI disk. The HI column density in these disks peaks at only $10^{20} \text{ atoms cm}^{-2}$, so, despite the large HI reservoir, no significant star formation is occurring. These HI disks will evolve only very slowly and will remain as purely gaseous disks for very long periods of time, provided the environment is not too hostile for these disks.

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